Physiologic Response to Microgravity

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Abstract-**Physiology in microgravity is a challenging field of research because of limited resources. Though humans have been in space for 50 years most meaningful data has been collected only within the last 15 years. While expensive studies with small sample sizes make obtaining and interpreting data difficult, some general conclusions about the human physiological response to microgravity can be drawn. A redistribution of bodily fluids is believed to initiate change in cardiovascular and respiratory function. The mechanisms for these changes have been studied very little are not well understood. Long term effects of microgravity on the body have been impossible to study in the past. Larger studies must be done for increased time periods in order to better characterize the underlying physiological mechanisms involved in the body's response to microgravity.**

I. INTRODUCTION

Physiological studies in microgravity are relatively young. Mostly all knowledge in the area has been collected over only the last 50 years. The first living animal to be sent into space was the Soviet dog Laika in November 1957, and the first human to enter space was Yuri Gagarin on April 12, 1961 [10]. Studies that were done early on were not very sophisticated and many times the control conditions were insufficient to render meaningful data. The most valuable studies of physiology in space were done in Spacelabs in the 90s. Spacelab was a reusable laboratory carried into orbit by the space shuttle that was designed to allow scientists to do experimentation in microgravity under controlled conditions. In June 1991, a Spacelab devoted to life sciences was launched into orbit where major experiments involving cardiovascular and pulmonary function and other physiological responses were performed [10]. This mission produced much of the knowledge of human physiology in microgravity that is known today.

Physiological systems of animals have adapted to the earth's gravitational field over their entire existence. These adaptations are more pronounced in terrestrial species with great height. For example, the cardiovascular system in giraffes, ostriches, and tree climbing snakes have sophisticated mechanisms that provide blood flow to the brain and restrict pooling of blood and swelling in tissues of the lower extremities. Because humans spend much time in the upright position, they have also developed mechanisms to regulate blood flow throughout the body. When considering that these mechanisms are designed to compensate for gravity, it seems logical that physiology will be affected by prolonged weightlessness.

The cardiovascular system is significantly agitated by loss of gravity. It has long been thought that a headward shift in bodily fluids is experienced when gravity is eliminated. "Because humans are predominantly upright creatures, with the majority of the blood located below heart level, gravity has a profound effect on the mechanical distribution of fluid within the cardiovascular system. When hydrostatic gradients are removed, such as changing from the upright to the supine position or exposure to microgravity, blood is translocated from the lower part of the body towards the chest virtually doubling the amount of blood within the heart [6]." This shift in fluid distribution is considered to produce a transient increase in central blood volume. The heart responds to the increase in volume and increases the stroke volume according to the Frank-Starling mechanism. The increase in stoke volume is detected by stretch receptors in the heart and interpreted as an increase in total blood volume. This triggers what is known as the Gauer-Henry reflex [11]. Atrial distension results and increased headward blood pressures reduce vasopressin secretion and sympathetic nervous activity [5]. The reduced sympathetic outflow depresses the renin-angiotensin-aldosterone process [5]. The atrial distension also increases secretion of atrial natriuretic peptide [5]. The Gauer-Henry response is thought to increase urine production and reduce blood volume [5].

Pulmonary physiology in space is sometimes neglected because weightlessness has not caused adverse affects on the lungs of the astronauts. In contrast, microgravity obviously deteriorates other systems of the body including the cardiovascular system, muscles, and bones [5]. While it is a first priority in space research to study problems in physiology that would inhibit sustained living and production in space, the lung turns out to be very sensitive to gravity. Loss of gravity can cause marked changes in the distribution of blood flow in the lungs, ventilation, gas exchange, alveolar size, intrapleural pressures, and mechanical stresses in the lungs [5].

Many factors make physiology in space a challenging research topic. Sometimes data is not collected under rigorous laboratory conditions, but rather in uncontrolled field conditions. Prelaunch posture, psychological excitement, stress, medical problems associated with microgravity, environmental fluctuations in spacecraft, and other hurdles make data collection and interpretation difficult [5]. Another obstacle is the small sample sizes available which prevent adequate statistical comparisons [5]. Despite the difficulty in obtaining data, there are still conclusions that can be made about physiology in space.

II. BACKGROUND

1) Cardiac Response: Blood pressure are determined by five components on earth: (1) the dynamic pressure resulting from cardiac pumping against peripheral resistance to blood flow; (2) dynamic pressures due to inertial forces of blood during activity; (3) pressure due to the finite compliance of the systemic vasculature, especially the veins; (4) extravascular pressure of tissues and interstitial fluid; and (5) an intravascular hydrostatic pressure due to gravity or gravitational pressure [5]. The intravascular hydrostatic pressure is the component that changes in zero gravity. This pressure is defined at a certain point in the vasculature as the product of the density of blood (~1.06 g/ml), the magnitude of acceleration, and the distance of the point of interest above or below the hydrostatic indifference level (HIL) [5]. The HIL is the place in the circulation where hydrostatic pressure remains constant with acute changes in orientation of an organism with respect to the gravity vector [5]. The loss of gravity eliminates hydrostatic blood pressure gradients throughout the vasculature. The normal location for the HIL in humans is just below the diaphragm. The location of the HIL depends on the relative compliance of the vessels throughout the body. If the vessels in the lower body become more compliant, the HIL shifts to a lower point in the body. This shift causes changes in cardiac function due to differences in the cardiac filling pressure.

Arterial pressures around the level of the heart remain relatively unchanged in microgravity, but hypothetically the peripheral circulation experiences increased transmural pressures in the upper body and decreased pressures in the lower body. Figure 1 shows an expected change in distribution of tissue fluid and arterial pressures experienced during spaceflight. The darker areas represent more tissue fluid. The numbers represent arterial pressures in units of mmHg.

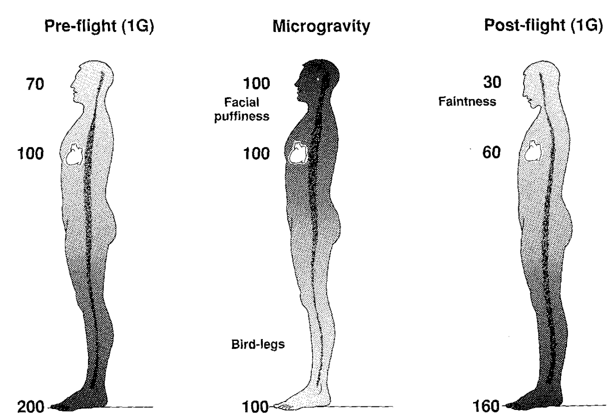

Figure 1: Hypothetical distribution of tissue fluid and arterial pressures experienced with spaceflight [5]

While the heart will be affected immediately by changes in filling pressures, it is reasonable that long term exposure to microgravity could alter the structure and function of the heart.

In order to understand the long term effects of microgravity on the cardiovascular system, it is important to recognize the immediate response which most likely initiates long term effects. The sudden loss of circulatory gravitational pressures could lead to central blood redistribution and transvascular fluid movements [5].

A study was done in 1987 in attempt to measure fluid redistribution [8]. These studies validate the movement of fluid away from the legs in microgravity. Figure 2 is leg fluid volume loss data collected from 3 astronauts over a 7 day mission. MD refers to the mission day.

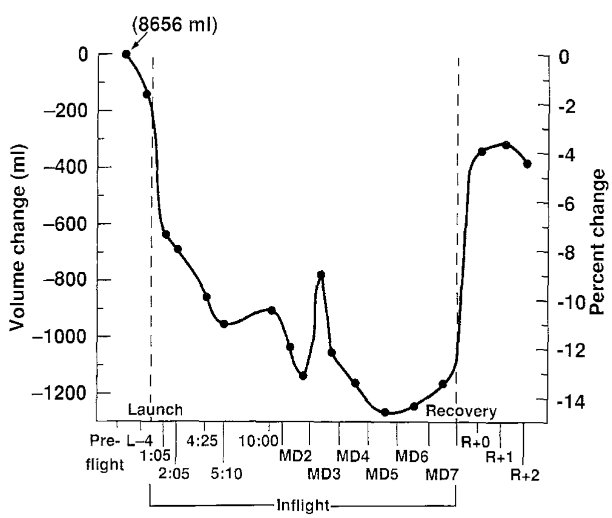

Figure 2: Leg fluid volume reduction during spaceflight [8]

The leg fluid volume decreased 7.7% or ~.6 liters in each leg by 1 hour after insertion into orbit [8].

In 1991, seven subjects were studied over a nine day mission to observe acute affects in cardiac output [9]. Figure 3 is a plot of stroke volume expressed as a percentage of preflight standing stroke volume.

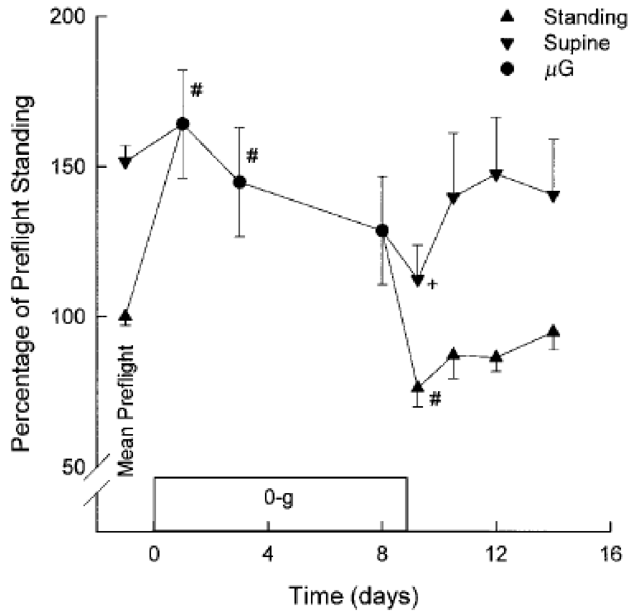

Figure 3: Stroke volume as a percentage of preflight standing stroke volume [9]

2) Respiratory Response: In comparison to other organs of the body, the lung occupies a large volume compared to its mass. The lung is designed to be less dense to provide air space for gas exchange to the blood. The compliant structure of the lung causes it to deform under its own weight. On earth, gravity causes regional differences in lung bloodflow, ventilation, gas exchange, alveolar size, intrapleural pressure, and mechanical stress [5]. It is reasonable to think that these regional differences will be reduced or eliminated in microgravity.

Experiments were done under parabolic flight conditions in attempt to evaluate blood distribution in the lungs at 0g, 1g, and 2g [7]. Subjects hyperventilated in order to reduce PCO_2 in all regions of the lung. The subjects then held their breath for 15 seconds and PO_2 and PCO_2 was measured with a mass spectrometer during subsequent vital capacity expiration. The idea was that PO_2 and PCO_2 would change in opposite directions at a rate determined by bloodflow per unit volume in any region of the lungs. Cardiogenic oscillations are caused by preferential emptying of certain regions of the lung more than other regions [7]. Therefore, the size of cardiogenic oscillations during exhalation would be a measure of the topographical inequality of the bloodflow throughout the lungs. Figure 4 shows the PO_2 and PCO_2 during 0g, 1g, and 2g. The insets are cardiogenic oscillations amplified from the signals.

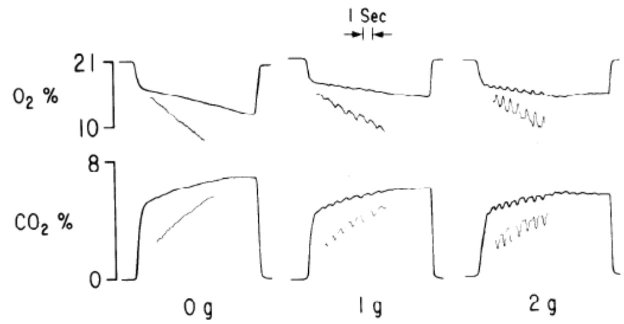

Figure 4: Effect of short periods of 0g, 1g, and 2g on the inhomogeneity of pulmonary bloodflow as measured by cardiogenic oscillations [7]

The cardiogenic oscillations were exaggerated during increased acceleration and were almost eliminated during 0g. This is evidence for reduced topographical inequality of bloodflow in microgravity [7].

Figure 5 shows a plot of the magnitude of the cardiogenic oscillations as a function of acceleration.

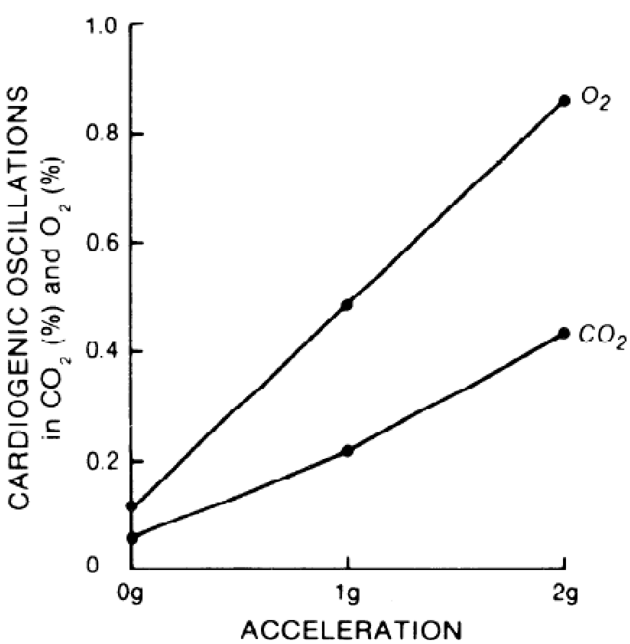

Figure 5: Cardiogenic oscillations as a function of gravity during PO_2 and PCO_2 measurements [7]

Similar studies were done to evaluate reduced inequality in ventilation in microgravity [7]. Inequality of ventilation was measured from single-breath nitrogen washouts performed with an initial bolus of argon at residual volume. Figure 6 are measurements using mass spectrometry of the nitrogen washouts done at 1g (top) and 0g (bottom).

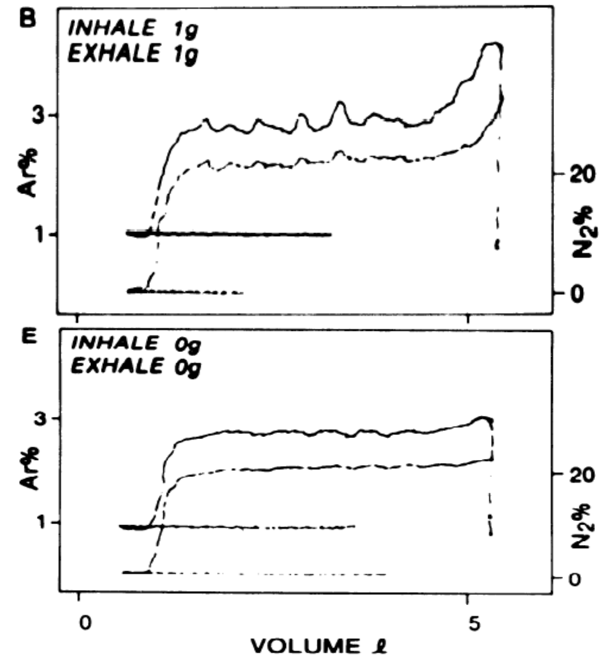

Figure 6: Single breath nitrogen washouts showing the effect of microgravity on ventilation [7]

Larger cardiogenic oscillations were seen at 1g indicating preferential emptying of the lungs [7]. There is also a terminal rise in the signal at 1g. This rise is a result of the upper region of the lung near the end of the expiration associated with airway closure, or failure of the basal region to empty for some other reason [7].

III. RESEARCH QUESTIONS

1) Central venous pressure: It is understood that gravity affects cardiac filling pressure and intravascular fluid distribution. Data collected validating increases in cardiac output due to loss of gravity, would imply that cardiac filling pressure must also increase. However, this is not the case. In order to understand the dynamics of these parameters it was necessary to measure the central venous pressure (CVP) which is the pressure at the right atrium of the heart.

Using catheters and pressure transducers the CVP was directly measured on 3 subjects aboard the Spacelab Life Sciences space shuttle flights [1]. Data collected provided a continuous CVP signal with pressures changes from earth to orbit. Figure 7 is the CVP data for 1 of the subjects.

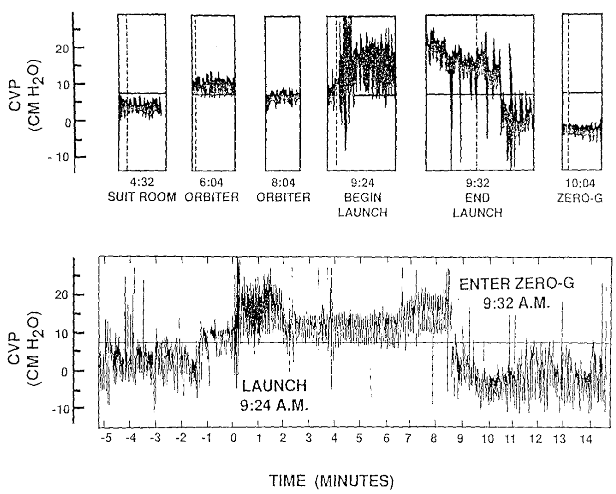

Figure 7: Central venous pressure at prelaunch, launch, and orbit

As expected, CVP increases during launch which is probably a result of anteroposterior compression of the thorax and abdomen caused by acceleration forces up to 3g [1]. Once in space, however, CVP dropped rapidly below preflight levels contradictory to expected increases with fluid volume redistribution [1].

These results pose interesting questions about the result of fluid redistribution in the body due to microgravity. The mechanisms that cause a simultaneous decrease in CVP and increase in cardiac output are not understood. The results indicating this illogical behavior in the cardiovascular system suggest that the effects of the fluid redistribution are more complex than initially thought.

Results from the CVP study are limited in that only three subjects were measured.

2) Long term exposure to microgravity: Perhaps one of the most difficult challenges facing space researchers is to understand physiological effects due to long term exposure to microgravity. A mission to Mars would take on the order of 1,000 days, which is three times longer than anybody has ever been in space so far [10]. Much physiologic data collected has been done during parabolic flight which allows for only 20-30s of weightlessness [5]. While initial physiologic responses may been seen, the rapid changes in acceleration do not allow for long term study.

The international space station is supposed to offer better opportunities to do long term studies. This project consists of components from the U.S., Russia, Europe, Japan, Canada, and other countries. Astronauts should be able to reside for extended periods to do more elaborate studies. Even with the space station, studies are very expensive and many times are delayed by many complications.

Medical devices that can perform easy, non-invasive measurements will be increasingly useful in advancing knowledge of space physiology. At this stage there is very little information about the effects of microgravity on physiology. Many questions will remain a mystery without better opportunities to test larger numbers of subjects for larger amounts of time.

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